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ABSTRACT

Described in this paper is a research approach used
in science and mathematics education at the University of Goteborg
(Sweden). The theoretical base of this approach relies on strong
interaction between theoretical studies and empirical studies in the
science classroom, with close cooperation between researcher and
teacher. Within this paper, knowledge formation models are described
concerning the distinction between "knowledge" and "knowing."
"Thought forms" concerning this distinction are defined. Relevant
examples are given relating this distinction to dialogue between
student and teacher, and teacher and researcher. Implications for
effecting change in teaching behavior are made. (CS)

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CONCEPT FORMATION IN MATHEMATICS AND
THE NATURAL SCIENCES; THE INTEGRATED
UPPER SECONDARY SCHOOL (9)

SOME THEORETICAL CONSIDERATIONS AND EXPERIENCES
RELATED TO RESEARCH AND DEVELOPMENT IN THE
TEACHING OF MATHEMATICS AND SCIENCE

Paper presented at the 'Cognitive Development Research
Seminar, Science and Mathematics Education; Session 20:
Research and Development (The research/practitioner inter-
face)', The University of Leeds, 17-22 September 1979.

Leif Lybeck

Abstract

The theoretical base of the research approach in Science and Mathematics Education at Göteborg has been evolved. It has emerged as an interaction between theoretical studies and empirical studies in the science classroom. The discipline Theory of Science and Research provides us with theoretical tools and the empirical studies are carried out in close cooperation with the teachers.

The experiences gained from the approach are described and related to research and development activities within the world of the school system and especially the researcher-practitioner interface concerning problem generation for future R&D. Some criteria on knowledge formation in Mathematics and Science Education based on our experiences are posed. The current and urgent debate in Sweden on R&D and in-service training in the teaching of mathematics and science needs a theoretical platform. Our contribution is an attempt to bring in the point of view of the researcher.

The research reported here has been financed by the National Swedish Board of Education.

In Sweden, teachers, teacher trainers and educators at university level have been discussing problems within the field of Mathematics Education and Science Education over a period of many years. Articles in Swedish magazines and Government reports from the latter part of the 19th century point to a tradition that has not resulted in introduction of Mathematics and Science Education at university level. In the past few decades, the continuous development of curriculum and study courses has resulted in development (D) projects in mathematics, biology, chemistry and physics. Especially, research (R) in school mathematics has been carried out at the Departments of Education. Similar research on the teaching of biology, chemistry and physics has been almost nonexistent. However, during this decade the Departments of Education have widened their interest for Science Education as reported by Lybeck (1977).

In fact, when I had the privilege of initiating the BMN ¹⁾ project (BMN is short for the Swedish name and can be translated as 'Concept formation in mathematics and the natural sciences'), there was no living tradition in Science Education in Sweden to connect our research approach with. Briefly, our research approach to Science Education at Göteborg has been described by Lybeck (1978a, 1979a). I have used notions introduced by professor Håkan Törnebohm, The Department of Theory of Science and Research, The University of Göteborg, in order to elaborate our approach. At the Institute of Education, The University of Göteborg, its theoretical base has been evolved. It has emerged as an interaction between theoretical studies and empirical studies in the mathematics and science classroom. The fruitfulness of our studies are themselves evidence for the proposed theoretical base of Science Education and arguments in favour of the applied perspective on science and research adopted from the above mentioned platform of Theory of Science and Research.

Introduction

In this paper I wish to convey some considerations and experiences on research (R) and development (D) related to the teaching of mathematics and science based on the work in the BMN project. The general theme concerns models on the researcher-practitioner interface.

First, I shall present an essential distinction which demonstrates the separation of two knowledge-producing activities.

The separation of two knowledge-producing activities

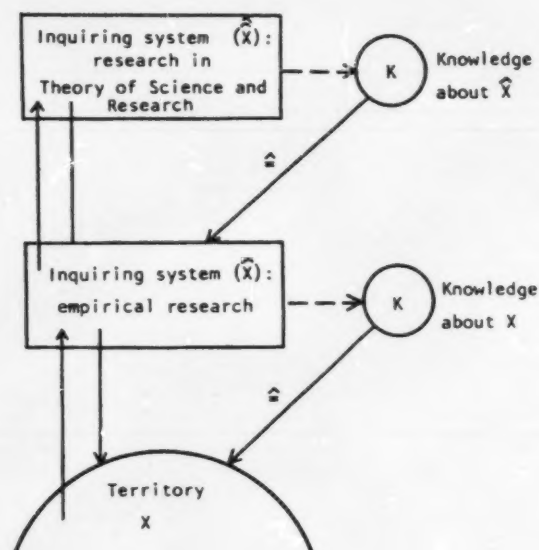


Figure 1. The relation of studies in Theory of Science and Research to empirical research.

Törnebohm (1976) distinguishes between two types of studies which refer to the same area of reality or territory X (Figure 1). In empirical science, research consists of studies treating an area of reality X , e. g. bodies in water (Archimedes' well-known hydrostatic problem). The research here is the inquiring system $\hat{X}$, which consists of the research group, different types of activities and their organization (in an extreme case the research group can consist of a single

person, e.g. Archimedes). The Theory of Science and Research $\hat{X}$ studies the inquiring system $\hat{X}$. (The arrow in Figure 1 refers to hypotheses framed in $\hat{X}$ and is intended to map features of an object X. There are other relations between $\hat{X}$ and X. Primary information flows from X to $\hat{X}$ through various channels, and the work done in $\hat{X}$ has a steering effect on its territory X.).

Two different types of knowledge are generated by $\hat{X}$ and $\hat{X}$ respectively (Figure 1). As physicist $\hat{X}$ Archimedes acquired knowledge of part of the physical reality by studying certain limited phenomena in X. Archimedes was able to describe and, to a certain degree, explain aspects of this reality by introducing concepts such as weight, displaced volume, 'lifting power', 'density', etc. As researcher $\hat{X}$ we acquire knowledge about $\hat{X}$ by finding out or reconstructing the method used by the historical person Archimedes, i. e. by asking questions such as: How did Archimedes plan his experiments? What theoretical assumptions did he make (assumptions that are purely hypothetical)? What instruments did he use to test his hypotheses? What were the theories that resulted from his activities, etc? It is important to note that the reconstruction does not have to concern Archimedes as a historical physicist but rather the notion of the 'ideal researcher type'. Other physicists have already developed the Archimedian research programme. The researcher $\hat{X}$ wants to ask questions such as: What did the importance of Archimedes' hydrostatic theory have for theory development and concept formation? Can the hydrostatic theory be utilized in the development of an aerostatic theory? And if so, how are hydrostatic's 'density' and 'pressure' concepts affected? The Theory of Science and Research forms knowledge on both historical case studies and how research is carried out today.

The human creative activity in $\hat{X}$ leads to knowledge about X. These products or results of the research $\hat{X}$ are lifting power, density, pressure, models, theories, etc. In production, i. e. the research process, the researchers utilize concepts such as hypothesis (H), instrument (I), problem (P), criticism (Cr), tactical plans (Pl), experiment, data, re-

search group, etc. The researcher $\hat{X}$ is interested in the researchers' $\hat{X}$ utilization of these sets of concepts in relation to the phenomenon studied in X . Activities within the empirical research $\hat{X}$ consist of the phenomena constituting the territory for the research in $\hat{X}$. In order to describe and explain the phenomena within $\hat{X}$ the researchers in the field of the Theory of Science and Research introduce their own concepts and models, e. g. those shown in Figure 1. Törnebohm (1978) has thus developed the triad (H, I, P) or the sequence of triads $\rightsquigarrow(H, I, P)\rightsquigarrow$ to the pentad (H, I, P, Cr, Pl); the sequence of pentads $\rightsquigarrow(H, I, P, Cr, Pl)\rightsquigarrow$ represents a running research programme where the pentad ($H_0, I_0, P_0, Cr_0, Pl_0$) represents an initial research programme. A triad (H, I, P) is to be looked upon as a research result. Sequences of the pentads are models of scientific investigations. We note only that the researchers' paradigm has steering effects on the components of the pentad.

Briefly, we can distinguish three levels. Levels 1 och 2 represent the product respectively the process aspects of the empirical research $\hat{X}$ (let us say related to the levels X and $\hat{X}$ in Figure 1). Level 3 corresponds to the reflective activities of the researchers $\hat{X}$ upon themselves and their inquiring system $\hat{X}$. It is the task of a service-oriented Theory of Science and Research to evolve situations, where the researchers $\hat{X}$ articulate their 'knowing' and tacit assumptions as well as previously not articulated knowing on level 3. The dialogue between the researchers $\hat{X}$ and $\hat{X}$ concerning level 3, and, of course, levels 1 to 2 may be transformed into knowledge, and the knowledge about the inquiring system $\hat{X}$ is a level 3 knowledge.

Törnebohm's Theory of Science and Research emphasizes the content and context dependencies of the researchers' conceptions of knowledge and concepts through their direct relation to the studied phenomenon. For our service-oriented Theory of Science and Research it is a prerequisite that the researchers $\hat{X}$ have intimate knowledge of empirical research of kind

I shall now apply the three distinct conceptual levels for the development of theory and studies in Science Education and Mathematics Education.

A model for studies in the fields of Science and Mathematics Education

The levels 1 and 2 correspond to the most important goals for teaching in physics and chemistry in the integrated upper secondary school. Concept formation takes place on two quite separate but concurrent levels, i. e. research's product aspect and its process aspect (method of working). Mathematical concepts play a decisive role in this concept formation, e. g. the concepts of proportion and proportionality when concepts such as density, concentration, etc. are introduced. The mathematical concepts are introduced as instrument I in the above-mentioned pentads (H, I, P, Cr, Pl) and influence concept formation within physics and chemistry. Thus, the study of the students' conceptions of concepts in the natural sciences implies a study of mathematical concept formation.

The above-mentioned types of concepts and concurrent concept formations which comprise the central part of the content of the BMN project's mapping of the students' spontaneous conceptions as they are expressed in interviews or in student-student, student-teacher or student-researcher dialogues in the classrooms and laboratories. In my view, studies of the student-student and student-teacher dialogues constitute the most essential part of the empirical foundation for research in the field of Science and Mathematics Education and its theory development.

Swedish courses of study in biology, chemistry and physics have been influenced by larger curriculum projects (BSCS, CHEM-study, PSSC, HPP, Nuffield, etc). Behind these projects we can trace the didactic concept 'the student as the small researcher'. It has been criticized, but let us combine it

with the idea of the three levels.

The researcher $\hat{\hat{X}}$ and the researcher $\hat{X}$ discuss on the three conceptual levels (let us say related to the levels X , $\hat{X}$ and $\hat{\hat{X}}$ in Figure 1). As a consequence of the didactic concept, the following model may be introduced (Figure 2).

$$\hat{\hat{C}}_T \xleftrightarrow{\quad} \hat{\hat{C}}_S \quad (3)$$

$$\hat{C}_T \longleftrightarrow \hat{C}_S \quad (2)$$

$$C_T \longleftrightarrow C_S \quad (1)$$

Figure 2. C is short for conceptual contexts on the different levels 1-3. They can be separated into one part for the teacher (T) and another part for the student (S) on the three levels.

$\longleftrightarrow$ denotes a dialogue and $\xleftrightarrow{\quad}$ a not so well-developed dialogue.

The content of the dialogue on level 1 concerns the product aspect, i. e. concepts such as weight, lifting power, density, etc., while level 2 is thought of as corresponding to the process aspect, i.e. everyday work where concepts such as hypothesis, instrument, problem, criticism, planning, experiment, data, team, etc. are used. By means of dialogues the teacher presents views that enable the teaching process to advance at the same time as the students make their own views known. Thus, the teaching process takes place by means of interaction on the different levels.

I would now like to present the relation between the notion 'knowing' as it has been used here and knowledge in order to bring into greater relief the proposed model with special re-

ference to the practitioner-researcher interface.

Body of views, knowing and knowledge

I now intend to discuss the role of the teacher and of the researcher in R&D. I shall use the terms body of views, knowing and knowledge, which were introduced by Törnebohm (1978a), in order to promote a certain degree of ordered reasoning and in order to be able to elucidate problems existing in the relationship between practitioner and the researcher.

A teachers's body of views includes conceptions of how teaching should be carried on. Similarly, the researcher has a research paradigm that guides his choice of problems and the way in which they should be solved. The researcher's paradigm is decisive for the formation of the problems. The research paradigm that can be shared by several researchers is one part of the individual researcher's body of views. It is only by means of a dialogue between the teacher and the researcher that conscious and unconscious conceptions can be made knowable (cf. the dialogue researcher $\hat{X}$ and researcher $\hat{\bar{X}}$ or the dialogue student-teacher in the proposed model in Figure 2). The teacher's and the researcher's knowing is of fundamental importance and what are decisive are the differences in their knowing and knowledge.

Törnebohm (1978a) divides the individual's knowing into two parts of particular importance in this context as follows:

1. Views acquired by the individual as a result of his own experiences and his own thoughts and
2. Views formed as a result of reading and teaching (cultural heritage).

In our studies of the students' conceptions of the density concept (level 1) we found that some of them thought that 'a stone sinks because it is heavy' while others were of the opinion that 'the stone sinks because it is heavier than water'. These assertions are examples of qualitatively different conceptions that are part of the students' knowing as

well as being part of their individual bodies of views. Their knowing is functional and as a rule is not questioned in the world of everyday physics. These 'knowing forms' or thought forms are adequate in their context.

An important realization that is now part of the reader's and my bodies of views is that one ought to make a clear distinction between knowing, which is part of the individual's body of views, and knowledge, which is formed through investigations and reported scientifically. As a consequence of what has been said here, one should distinguish between theories concerning knowing and theories concerning knowledge.

We are now in a position to state that a large part of the INOM²⁾ group's (a collective name for several research projects at the Institute of Education, The University of Göteborg. INOM is a Swedish abbreviation for 'Learning and the conceptions of the world around us'.) studies concern the individual's body of views and in particular his knowing related to certain phenomena in the physical reality. This means that together we try to form knowledge and theories about knowing. In the BMN project I have called certain forms of knowing thought forms. In the studies, Lybeck (1978b) demonstrated that they have their equivalents in forms of knowledge within the scientific disciplines. This does not mean that I have drawn the conclusion that knowledge and knowing are organized in the same way even if they are related to the same phenomenon. In epistemology one studies the way in which knowledge is organized. A 'knowing theory' should have the task of studying the way in which knowing is organized. The latter task necessitates continued intensive empirical studies as well as theoretical studies based on e. g. the Theory of Science and Research, the Philosophy of Science, the History of Science, etc. in order to determine how individuals transfer their knowing to knowledge, i. e. from something personal to something public.

I would now like to once again discuss the conceptual contexts presented in the model in Figure 2. They constitute problem fields which, based on arguments from the Theory of Science

and Research, are separable domains within the field of Science and Mathematics Education.

Problem fields for R&D in the field of Science and Mathematics Education

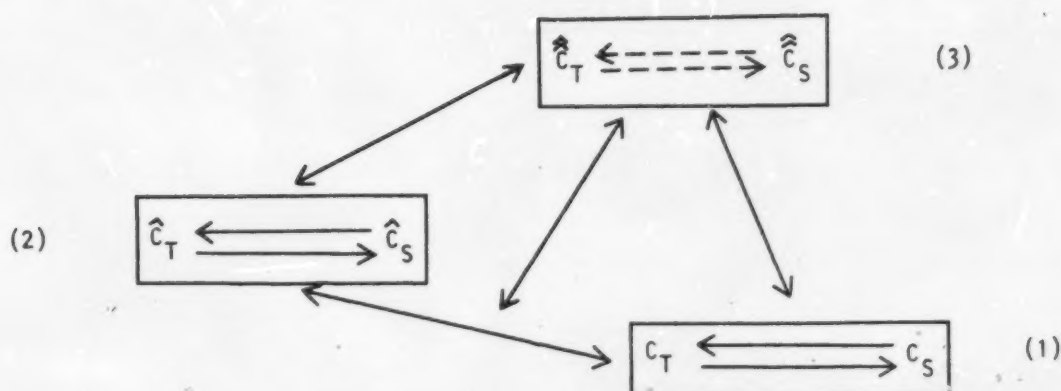


Figure 3. The notations are the same as in Figure 2.
 $\longleftrightarrow$ denotes different types of relations.

On each of the levels 1, 2 and 3, the teacher's and the students' conceptual contexts form problem fields for R&D. The problem fields, which we perhaps ought to name 'knowing fields', are studied empirically by means of interviews and recordings in classrooms and laboratories.

In interviews with individual students we are able to map their knowing with regard to such concepts as density, proportionality, etc. on level 1 as well as concepts such as hypothesis, instrument, problem, data, experiment, etc. on level 2. These levels correspond to the product and process aspects in the human activity (research) that produce knowledge of the phenomenon studied in its physical surroundings. The levels 1 and 2 also correspond to the content of the teaching. Similar studies of teachers' knowing on levels 1 and 2 should also be carried out in accordance with our experiences. Level 3

corresponds to the teacher's and the student's bodies of views concerning teaching. The student needs help in expressing both conscious and unconscious conceptions of his knowing concerning the goals of the teaching. It is on level 3 that knowing concerning the method of working is formulated. Level 2 in the model corresponds to the actual teaching process. The student can participate in the teaching (level 2) without necessarily having thought about what its goals are (level 3).

Interviews with students on level 3 constitute a mapping of their knowing concerning levels 1 and 2 as aspects of the teaching. At the same time, their conceptions of the relationship between levels 1 and 2 in the concept-forming and knowledge-forming process in the subject are mapped. Here, it must be emphasized in particular that corresponding mappings of teachers', student teachers' and other adults' knowing on level 3 are not only extremely desirable but also an important part of the approach reflected by the model.

Recordings of the actual teaching provide data that supplement the mappings of the qualitative different conceptions on levels 1, 2 and 3. The two-dimensional category diagram of the students' (ages 16-17) qualitatively different conceptions of the concepts of proportion and proportionality presented by Lybeck (1978b, 1979b, c) was used in the analyses of student-student and student-teacher dialogues during the actual teaching (1979b, pp 45-47, 1979c). The classroom recordings show that certain thought forms do not come into play during the teaching itself; this results in some of the students not realizing how and why concepts such as density and speed are formed with mathematics as the instrument. Consequently, these students do not participate in the teaching on their own terms. In fact, it can be said that the resources the students themselves constitute are not utilized during the teaching and two conceptual worlds are formed: everyday physics and school physics. Throughout the school year, the researcher and the teachers in our experimental classes recorded discussions with the students and between students during laboratory work and group work. This data generation provides a longitudinal picture of the changes in the students' knowing. An extremely

interesting phenomenon is the perspective shifts in the approach of students who have been documented during the school year. These perspective shifts (new insights) must be seen as having great importance for discussions on the method of working in the natural science teaching. During frontal teaching or while the teacher is talking with groups of students the teachers sometimes express their conceptions of the teaching on level 3 and state quite clearly why they are partial to certain thought forms on e. g. level 1. On such occasions they articulate as teachers intimate knowledge. (Example given in Lybeck (1979c).).

By means of interviews with teachers and students and recordings of learning and teaching situations the researcher is able to sketch real pictures. Many ideal pictures and even anecdotes live on in the form of traditions in the teacher training. Here, practitioners and researchers have a central and common task, namely to jointly produce real pictures of learning and teaching situations as they actually occur in school. On the practitioner-researcher interface, both sides are responsible for the establishment of fruitful dialogues. One stage in such talks could consist of the researcher describing his view of R&D activities by sketching models as has been done in this paper. In Figure 4 I shall sum up some of the essential features of the activities of the BMN project.

In our case, the researcher participates in two types of information flow called the primary information flow and the secondary information flow by Törnebohm. The primary information flow is based on the object of the studies. In my opinion, the qualitatively different conceptions of and thought forms around the subject content that can be mapped through interviews and classroom observations are of fundamental importance for the empirical and theoretical development of Science and Mathematics Education. At the initial stage, where we now are, exploratory studies dominate. They can be carried out on the three levels quite separately. These consist of legitimate and purely pedagogical research tasks, e. g. how students and teachers perceive learning and teaching, i. e. on level 3. The dimension in the research activity em-

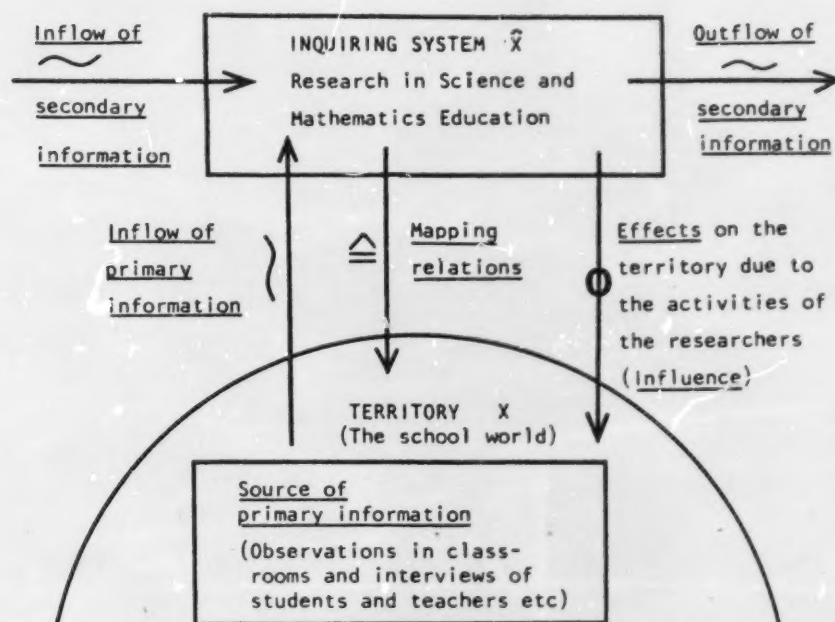


Figure 4. Some features of the research within the field of Science and Mathematics Education.

phasised by our efforts constitutes strategic planning from level 1 to level 2 and to level 3. This strategy cannot be refined since the levels interact. According to our model, the distinctive feature of Science and Mathematics Education (or History Education etc.) consists of a focusing on the conceptions' content and context dependence. The secondary information flow refers to other inquiring systems. The Natural Sciences and Mathematics are closely related as are other inquiring systems in the field of Science and Mathematics Education. Other closely related disciplines are Education, Educational Psychology, Cognitive and Developmental Psychology, the Theory of Science and Research, the Philosophy of Science, the History of Science and the History of Mathematics. Our import of concepts and intellectual instruments from the Theory of Science and Research is an

example of the inflow of secondary information.

I shall now point to some of the demands placed on our research and the criteria as regards its formation of knowledge.

Concerning demands on the research and criteria of its formation of knowledge

We place special importance on the fact that the researcher has an intimate knowledge of the object of the studies. Consequently, the research team should include one or more persons who teach the subjects in question. The researcher should also become well acquainted with the teaching process involved by attending lessons during a long period of time. Thus, we reject the idea that a person can, from the outside and in a 'neutral way', observe and acquire knowledge of the object of the studies.

Naturally, the researcher often plays the part of a passive observer, but during the dialogues with students and teachers it is not meaningful to consider oneself to be a completely 'objective' and 'neutral' observer since the researcher is in fact a part of the data-generating system. In this context, the researcher can be seen as a measuring instrument with a certain instrument theory. It is particularly important that the researcher's instrument theory is articulated before the actual study. Thus, prior to the Archimedes recordings in the classroom we wrote down our reconstruction based on the platform of the Theory of Science and Research of the knowledge forms that could be considered possible. This, together with developmental-psychological knowledge of the physical phenomena increased the researcher's ability to register logical distinctions in the students' spontaneous statements during the lessons presented by Lybeck (1979b, c). It should be noted that the instrument theory includes the researcher's intimate knowledge of the teaching, teacher training profession, etc.

An important requirement is that recorded teaching and learning situations must be genuine events that occurred in school. Naturally, it is the teacher who is responsible for the teaching even if the experiments are carried out on the researcher's suggestion. It is during the practitioner-researcher dialogue that the researcher tries to gain approval for the testing of hypotheses. Testing takes place only if the teacher considers the experiment to be consistent with his views of how the students should be taught, otherwise foreign elements might have an undesirable effect on the teaching itself. Furthermore, the researcher has a responsibility towards the students to avoid possible failures. In the dialogues that take place during the duration of the study the practitioner and the researcher develop and exert an influence on their knowing of the teaching process. One can say that their intimate knowledge is going through a refining process. The experimental teachers can be stimulated into renewing themselves and D works while data is being formed for a R task.

In analyses of the students' answers in the study of their qualitatively different conceptions of the proportion and proportionality concepts (level 1) presented by Lybeck (1978b, 1979b, c), the description was made in terms of the content. Algebra's symbol language was used in the interpretation of the students' verbal quantifications, and aspects of the concept of function, with respect to the general line of reasoning leading to the students' solutions. By describing the students' answers in terms of the content, results are obtained that can be utilized more easily by the teachers. This is thus a practitioner's demand on the research results.

It is a fact that old theories in the instrument theory influence the generation of data. The fact that humanistic knowledge from the Theory of Science and Research and the History of Science and Mathematics has provided valuable ideas and is, as it were, built into the interviewer-researcher's instrument theory does not mean that the production of knowledge takes place in an uncontrolled manner.

It is namely the researcher's task when analysing data to demonstrate that the hypothesis can be confirmed in the new context, i. e. in the empirical context of Science or Mathematics Education.

Above, we have given an indication of how the dialogues between the practitioner and the researcher leads to questions that can be made knowable and transformed into problems of two types, namely, problems P_R for the R departments and problems P_D for the D departments. These problems are generated in the world of the school. In the R departments solutions of P_R are accepted as knowledge. These solutions of P_R , knowledge or even new hypotheses can be judged by the practitioners as being relevant or can be rejected. The practitioner's judgement does not necessarily strip the researcher's result of its knowledge status. The problems P_D can be generated by the teachers themselves since they wish to change their knowing. Other P_D 's can be produced as the result of practitioner-researcher interaction. Thus, the research results are added to analysis instruments that can be applicable in D work. The analysis instrument for the concepts of proportion and proportionality can be applied in other subjects and in other contexts with the intention of constructing fields of activities. The instrument can also be used in curriculum work. An important aspect of these activities is that the knowledge that is built into the analysis instrument guarantees in advance, so as to say, meaningful tasks that lead to results in D work. The research task is not given the same guarantees. However, D work may lead to alterations in the analysis instrument. In such a case it is a valuable incentive in D work.

During the dialogue between the practitioner and the researcher it is the task of the researcher to try to change the teacher's knowing about teaching by means of his knowledge. The dialogues must be based on insights concerning the different tasks to be carried out by the practitioner and the researcher. These tasks are complementary. The

practitioner (teacher) and the researcher are united in an effort to transform knowing about the teaching into knowledge. Questions that lead to problems concerning how certain phenomena in the teaching are to be made knowable may lead to the question: Is the knowable worth knowing? Here, the two sides have a large, joint responsibility. Here, I shall do no more than imply that interested parties outside the school world have reason to make demands on R&D work.

Like teachers, researchers have professional interests and specific professional competence. The former concerns mainly research but also development work. The teacher's competence should, in addition to teaching competence, also include the potential to increase his ability to carry through D work. It is the interests of both researchers and teachers that co-operation can take place in a more planned way.

Notes

1. BMN is short for the Swedish name and can be translated as 'Concept formation in mathematics and the natural sciences'. During the school years 1975-79 the project was sponsored by the National Swedish Board of Education. The studies concern mainly mathematics and physics teaching in the integrated upper secondary school, the natural science (N) line and the technology (T) line, ages 16-18.
2. INOM is a collective name for several research projects at the Institute of Education, the University of Göteborg. INOM is a Swedish abbreviation for 'Learning and the conceptions of the world around us'. The scientific leader is professor Ference Marton. The BMN project constitutes a part of the INOM group, which activity has been briefly mentioned by Lybeck (1978a, 1979a).

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